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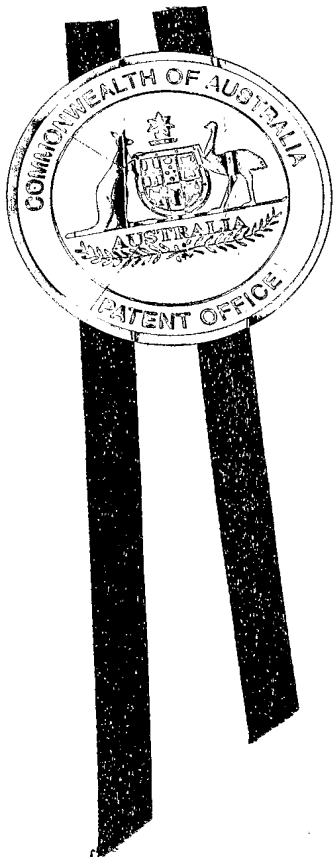


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WITNESS my hand this  
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A handwritten signature in black ink, appearing to read 'J. Peisker'.

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AUSTRALIA  
Patents Act 1990

PROVISIONAL SPECIFICATION

**Applicant(s):**

THE UNIVERSITY OF SYDNEY

**Invention Title:**

APPARATUS FOR PLASMA TREATMENT

The invention is described in the following statement:

## APPARATUS FOR PLASMA TREATMENT

### Field of the Invention

5           The present invention relates to an apparatus for plasma treatment of a substrate surface.

### Background of the Invention

10           Plasma treatment is used in a variety of processing methods. For example, plasma treatment is used in microelectronics, optics and photonics to coat surfaces of substrates or to etch structures into the substrate. In particular, if plasma treatment is used to coat the  
15           substrate, it is often important to treat the substrate uniformly so that variations of properties of the coating, such as the thickness of the coating, along the substrate surface are as small as possible. For example, for photonics applications, such as dense wavelength division  
20           multiplexing (DWDM) filters, it is desired that the thickness of coating does not vary more than 0.05% along the coated substrate.

          In general it is very difficult to generate a plasma that has a uniform density profile. The density profile of  
25           the plasma depends on many parameters such as gas flow rate, gas flow distribution, gas ratios, pumping rate, plasma energy and geometrical constraints of the source that generates the plasma. Attempts have been made to design plasma sources that provide improved uniformity.  
30           For example, plasma sources have been designed that comprise electrodes having a large number of gas outlet openings distributed evenly over their surface, not dissimilar to a conventional "showerhead", and arranged so

that the gas flow distributed over the surface results in a more uniform plasma density profile. However, treatment of large substrates requires large and very expensive systems and coating of substrates with films that have a controlled thickness profile are not possible.

### Summary of the Invention

The present invention provides in a first aspect an apparatus for plasma treatment of a substrate surface comprising:

a plasma source for generating a plasma, the plasma source having at least one source electrode and a plasma-control electrode, and

a drive means for effecting a relative movement of the substrate relative to at least one of the or each source electrode and the plasma-control electrode,

wherein in use the plasma-control electrode is positioned adjacent the substrate to facilitate control of the plasma in the proximity of the substrate and the relative movement effects a predetermined plasma treatment of the substrate.

For example, the substrate may be larger than the diameter of the plasma. In addition, the drive means may be arranged so that one or both of the substrate and plasma source can be moved (eg by scanning) relative to each other. Therefore, the local properties of the treated substrate surface are less dependent on the density profile of the plasma which improves the uniformity of the treated substrate surface. In particular, it is of significant advantage that the thickness uniformity of a substrate coating is less.

dependent on the profile of the plasma and therefore can be improved. Further, the uniformity of other properties including structural, mechanical, chemical, optical and electrical properties of the coating may also be improved.

5       The drive means may also be arranged to effect the relative movement in a manner so that a predetermined and non-uniform substrate treatment is effected. For example, the drive means may be arranged to effect the relative movement in a manner so that a coating of a predetermined  
10   profiled thickness is deposited on the substrate. In one specific embodiment the drive means is arranged so that the surface is coated with a coating having a region of tapered thickness.

      The plasma-control electrode typically is positioned  
15   so that the substrate is between the or each source electrode and the plasma-control electrode. In this case, the substrate may be positioned on the plasma-control electrode. For example, if the substrate is flat, the plasma-control electrode may also be flat. In general,  
20   the plasma-control electrode may have any shape and typically is shaped to approximate the shape of the substrate.

      The plasma source typically is arranged to generate a reactive plasma in which the input gases form a chemical  
25   reaction product. In a specific embodiment the plasma source is arranged to generate a plasma enhanced reactive chemical vapour deposition process which deposits a coating onto the substrate.

      For example, the plasma source may comprise a  
30   magnetron source, a cathodic arc, a helicon plasma source with an antenna surrounding an insulating hollow cylinder or a hollow cathode source consisting of a cylindrical or other hollow conductor. In a specific embodiment, the at

least one source electrode is cup-shaped and arranged to receive an rf voltage signal. The or each source electrode may have a gas inlet and may be arranged so that in use the plasma is generated within the cup-shaped electrode and is directed towards the substrate.

In an alternative embodiment, the or each source electrode, which may for example be one of two source electrodes, comprises a number of spaced apart gas outlets. In this case gas may be provided from each gas outlet and this arrangement may result in a plasma that has a more uniform profile.

The plasma-control electrode typically is also arranged to receive an rf voltage signal and typically is positioned directly adjacent the substrate and arranged so that control of the energy of ions impacting the substrate from the plasma is facilitated.

The drive means typically is arranged to move the substrate relative to the or each source electrode. Additionally, the drive means may also be arranged to move the substrate relative to the or each source electrode and to the plasma control electrode. The drive means may be arranged to scan the substrate relative to at least one of the electrodes in an XY coordinate system. Alternatively or additionally, the drive means may be arranged so that the substrate is rotated relative to at least one of the electrodes and the source may be moved relative to the substrate rotation axis by a rotating arm.

The drive means may be arranged so that the velocity of the relative movement and thereby the local plasma treatment time per unit substrate area can be controlled. For example, the drive means may be arranged so that by controlling the scanning velocity the thickness profile of the coating can be controlled.

The apparatus may further comprise a monitoring system that is arranged to monitor the plasma treated substrate. For example, if the substrate is larger than the plasma diameter, it is possible to monitor the treated  
5 substrate outside the plasma area to obtain information about the plasma treatment that may be used to improve and/or control the plasma treatment of the substrate.

In one specific embodiment the monitoring system is an optical system that is arranged to irradiate the  
10 substrate with a broadband optical wavelength spectrum. In this embodiment, the monitoring system is also arranged to receive reflections from the plasma treated substrate which may be analysed to obtain information about properties of the plasma treated substrate such as the  
15 thickness of substrate coating, optical, chemical or structural properties.

The apparatus typically comprises a guard wall arranged about at least one of the or each source electrodes to confine the plasma. For example, the guard  
20 wall may be arranged to directly confine the plasma or to confine flow of gas. The guard wall may be arranged so that a voltage potential may be applied to the guard wall that may further control properties of the plasma such as the confinement of the plasma.

25

The present invention provides in a second aspect a method for plasma treatment of a substrate surface comprising:

generating a plasma,  
30 controlling the plasma in the proximity of the substrate and

moving the substrate relative to the plasma to effect a predetermined plasma treatment of the substrate.



The plasma may be a plasma of a gas or a vapour which may or may not contain atoms or ions derived from a solid source by sputtering or evaporation.

5           For example, movement may be controlled so that the substrate is coated with a coating having a predetermined thickness profile.

          The method may comprise the additional step of controlling the plasma treatment by controlling an rf  
10       voltage applied to electrodes located on either sides of the substrate. For example, the same rf voltage may be applied to at least source electrode and to a plasma-control electrode. Alternatively or additionally, controlling of the plasma treatment may be effected by  
15       selecting respective rf voltages that are applied to respective electrodes. The respective rf voltages may have differing phase, amplitude or frequency.

          Throughout this specification, the term "rf voltage" is used for voltages having any frequencies including  
20       extremely high or extremely low frequencies. Further, it is to be understood that alternatively the plasma source may be arranged for operation by a dc voltage.

          The present invention provides in a third aspect a  
25       substrate that is plasma treated by the above-defined method or that is plasma treated by the apparatus defined above.

          The invention will be more fully understood from the  
30       following description of specific embodiments. The description is provided with reference to the accompanying drawings.

### Brief Description of the Drawings

Figure 1 shows a cross-sectional representation of an apparatus for plasma treatment of a substrate surface according to a first specific embodiment, and

5        Figure 2 shows a cross-sectional representation of an apparatus for plasma treatment of a substrate surface according to a second specific embodiment.

### Detailed Description of Specific Embodiments

10        Initially referring to Figure 1, an apparatus for plasma treatment of a substrate surface according to a first specific embodiment is now described. The apparatus 10 comprises a hollow cathode 12 and a plasma-control electrode 14. The chamber wall can operate as the second  
15        source electrode. Substrate 16 is movable relative to the hollow cathode 12 and the plasma-control electrode 14 by drive 16. In operation a plasma enhanced reactive chemical vapour is generated by hollow cathode 12 so that substrate 16 is coated with a coating (not shown).

20        During operation, drive 18 moves substrate 16. Drive 18 is arranged to scan the substrate relative to hollow cathode 12 and plasma-control electrode 14 in an XY coordinate system. Drive 18 can also be set up to rotate substrate 16. Further, the scanning or rotation speed  
25        that is effected by drive 18 can be controlled so that substrate 16 can be coated with a coating having a predetermined thickness profile. Further, because the substrate is moved relative to hollow cathode 12 and plasma-control electrode 14 the uniformity of the coating  
30        is less dependent on the uniformity of the plasma profile. Therefore, it is possible to coat relatively large surfaces either with a coating having a predetermined

thickness profile or with a coating having a substantially uniform thickness.

In this embodiment, the apparatus 10 is positioned in a vacuum chamber (not shown). The plasma source consists of a hollow cathode 12 and a cup shaped electrode 20, an electrical connection 22 and a gas inlet 24. In use, an rf voltage having a frequency of a few 10 kilo Hertz is applied to electrical connection 22 and gas is directed into cup shaped electrode 20 through inlet 24.

10       The substrate 16 is positioned between the plasma-control electrode 14 and the hollow cathode 12. In this embodiment, the substrate 16 is positioned immediately adjacent the plasma-control electrode 14. The plasma-control electrode has an electrical connection 26 that is  
15       arranged to receive an rf voltage. In use, a plasma is generated by the hollow cathode 12 which is controlled and also supported by plasma-control 14. For example, the energy of the plasma particles over substrate 16 can be controlled by adjusting the rf voltages applied to plasma-  
20       control 14 and to hollow cathode 12 relative to each other. The rf voltages can be adjusted so that they are of differing phase, amplitude or frequency. The position of the plasma-control electrode 14 adjacent and behind substrate 16 is particularly advantageous for controlling  
25       the plasma treatment properties on substrate 16. In general, the plasma-control electrode 14 approximates the shape of substrate 16. For example, in alternative embodiments substrate 16 may have an arc shaped cross-section or any other cross-sectional profile and the  
30       plasma-control electrode will then be shaped to approximate the shape of the substrate. The plasma-control electrode 14 may be connected to the same rf voltage source as hollow cathode 12 (the rf voltage source

is now shown). Alternatively, the rf voltages for the plasma-control electrode 14 and the hollow cathode 12 may be provided by separate rf voltage sources.

5 In this embodiment the apparatus 10 is arranged so that, during operation, reactive gas flows at least partially through the plasma region. In this specific embodiment, gas is inserted through gas inlet 24. Additionally or alternatively, gas may also be provided through any other port. For example, for the deposition  
10 of a silicon oxide-nitride coating, silane and nitrogen gases may be directed through inlet 24 and oxygen may be injected into the vacuum chamber through a port that is remote from the hollow cathode 12.

In this embodiment, apparatus 10 also comprises a  
15 guard wall 28. The guard wall 28 circumferences the hollow cathode 12 and thereby confines the extension of the plasma. For example, a voltage may be applied to the guard wall 28 and the additional voltage potential can be utilised to further confine and/or control the plasma.  
20 Further, the guard wall 28 can be utilised to control and/or confine the plasma by controlling and/or confining the flow of gases. In this embodiment the guard wall 28 has an opening 29 that has a diameter smaller than the extension of electrode 14. The distance between the  
25 substrate 16 and the guard wall 28 is smaller than the distance between the substrate 16 and the cathode 12. In this embodiment, the position of the guard wall 28 and therefore the plasma controlling and/or confining properties of the guard wall is adjustable.

30 In this embodiment the apparatus 10 further comprises an optical monitoring system 30. The optical monitoring system 30 comprises an optical radiation source 32 and a detector 34. The broadband radiation is generated by

optical source 32, directed to the substrate 16 and reflections are measured by detector 34. The detected optical signal is then analysed to obtain information about the plasma treated substrate 16 such as information  
5 about coating thickness, composition as well as optical properties of the treated substrate. In this embodiment optical monitoring is performed outside the plasma region. Due to the confinement of the plasma by the guard wall 28 it is possible to perform the optical measurements with  
10 improved accuracy. In particular, broadband wavelength spectrum monitoring can be achieved with reduced influence from the plasma. Single or multi-wavelength monitoring is possible but broadband monitoring has the advantage that the accuracy with which the properties of the treated  
15 substrate 16 are determined can be increased.

Figure 2 shows a cross-sectional representation of an apparatus for plasma treatment of a substrate surface according to a second specific embodiment. In this case the apparatus 40 comprises a "showerhead" type cathode  
20 having a large number of apertures which are connected to gas inlet 44 and arranged so that gas flows in the plasma region between cathode 42 and substrate 16. Because of this arrangement, the gas flow is more uniform throughout the profile of the plasma. Cathode 42 has an electrical  
25 connection 46 arranged to receive an rf voltage. In order to improve the confinement of the plasma, cathode 42 has a ring-like part 48 positioned on top of cathode 42.

Guard wall 28 has extensions 50 which further improve the confinement of the plasma. All other components of  
30 apparatus 40 are analogous to those of apparatus 10 shown in Figure 1.

Although the invention has been described with reference to particular examples, it will be appreciated

by those skilled in the art that the invention may be embodied in many other forms. For example, apparatus 10 or 40 may comprise drives that drive hollow cathode 12 and cathode 42, respectively, while the substrate 16 is stationary. The drive may or may not move the plasma-control electrode 14. In the case where it is not driven, the plasma-control electrode is sufficiently large in extent that it covers the region of interest of the substrate. Furthermore, it will be appreciated that any type of plasma generating electrode or cathode may be used. For example, the device may comprise helicon type plasma sources or magnetron or cathodic arc plasma sources. Further, a magnetic field may be utilised to further enhance the confinement of the plasma. In addition, it will be appreciated that plasma treatment is not limited to coating of substrate surfaces but may also be utilised to achieve etching of the substrate. This etching may be controlled in its intensity to achieve a controlled profile change of the surface.

20

The Claims Defining the Invention are as Follows:

1. An apparatus for plasma treatment of a substrate surface comprising:

5 a plasma source for generating a plasma, the plasma source having at least one source electrode and a plasma-control electrode, and

a drive means for effecting a relative movement of the substrate relative to at least one of the or each  
10 source electrode and the plasma-control electrode,

wherein in use the plasma-control electrode is positioned adjacent the substrate to facilitate control of the plasma in the proximity of the substrate and the relative movement effects a predetermined plasma treatment  
15 of the substrate.

2. The apparatus as claimed in claim 1 wherein the drive means is arranged to effect the relative movement in a manner so that a uniform substrate treatment is effected.

20

3. The apparatus as claimed in claim 1 wherein the drive means is arranged to effect the relative movement in a manner so that a predetermined and non-uniform substrate treatment is effected.

25

4. The apparatus as claimed in claim 3 wherein the drive means is arranged to effect the relative movement in a manner so that a coating of a predetermined profiled thickness is deposited on the substrate.

30

5. The apparatus as claimed in any one of the preceding claims wherein the plasma-control electrode is positioned so that in use the substrate is between the or each source

electrode and the plasma-control electrode.

6. The apparatus as claimed in claim 5 wherein the substrate is positioned on the plasma-control electrode.

5

7. The apparatus as claimed in any one of the preceding claims wherein the plasma-control electrode is shaped to approximate the shape of the substrate.

10 8. The apparatus as claimed in any one of the preceding claims wherein the plasma source is arranged to generate a plasma enhanced reactive chemical vapour.

15 9. The apparatus as claimed in any one of the preceding claims wherein the plasma-control electrode is positioned directly adjacent the substrate and arranged so that control of the energy of the plasma in the proximity of the substrate is facilitated.

20 10. The apparatus as claimed in any one of the preceding claims wherein the drive means is arranged to move the substrate relative to at least one of the or each source electrode.

25 11. The apparatus as claimed in claim 10 wherein the drive means is arranged to move the substrate relative to the or each source electrode and the plasma-control electrode.

30 12. The apparatus as claimed in any one of the preceding claims wherein the drive means is arranged to scan the substrate relative to at least one of the electrodes in an XY coordinate system.



13. The apparatus as claimed in any one of the preceding  
claims wherein the drive means is arranged so that the  
substrate is rotated relative to at least one of the  
5 electrodes.

14. The apparatus as claimed in any one of the preceding  
claims wherein the drive means is arranged so that the  
velocity of the movement and thereby the local plasma  
10 treatment time per substrate area can be controlled.

15. The apparatus as claimed in any one of the preceding  
claims further comprising a monitoring system that is  
arranged to monitor the plasma treated substrate.

15

16. The apparatus as claimed in claim 15 wherein the  
monitoring means is an optical system that is arranged to  
irradiate the substrate with a broadband optical  
wavelength spectrum.

20

17. The apparatus as claimed in any one of the preceding  
claims further comprising a guard wall arranged about at  
least one of the or each source electrode to confine the  
plasma.

25

18. The apparatus as claimed in claim 17 wherein the  
guard wall is arranged to confine flow of gas.

30

19. The apparatus as claimed in claim 17 or 18 wherein  
the guard wall is arranged so that a voltage potential can  
be applied to the guard wall that further controls  
properties of the plasma.

20. A method for plasma treatment of a substrate surface comprising:

generating a plasma,

controlling the plasma in the proximity of the .

5 substrate and

moving the substrate relative to the plasma to effect a predetermined plasma treatment of the substrate.

21. The method as claimed in claim 21 wherein the  
10 movement is controlled so that the substrate is coated with a coating having a predetermined thickness profile.

22. The method as claimed in claim 20 or 21 wherein the plasma is generated by a plasma source having at least one  
15 source electrode and a control electrode, and the method comprises the additional step of controlling the plasma treatment by controlling the rf voltage applied to the at least one electrode.

20 23. The method as claimed in claim 22 wherein the same rf voltage is applied to the or each source electrode and to a plasma-control electrode.

24. The method as claims in claim 22 wherein controlling  
25 of the plasma treatment is effected by selecting respective rf voltages that are applied to at least one of the electrodes.

25. The method as claimed in claim 24 wherein the  
30 respective rf voltages have differing phase.

26. The method as claimed in claim 24 wherein the respective rf voltages have differing amplitude.

27. A substrate treated by the method as claimed in any one of claims 20 to 26.

5 28. A substrate plasma treated by the apparatus as claimed in any one of claims 1 to 19.

DATED this 20<sup>th</sup> day of FEBRUARY 2004

10 THE UNIVERSITY OF SYDNEY

By their Patent Attorneys

GRIFFITH HACK

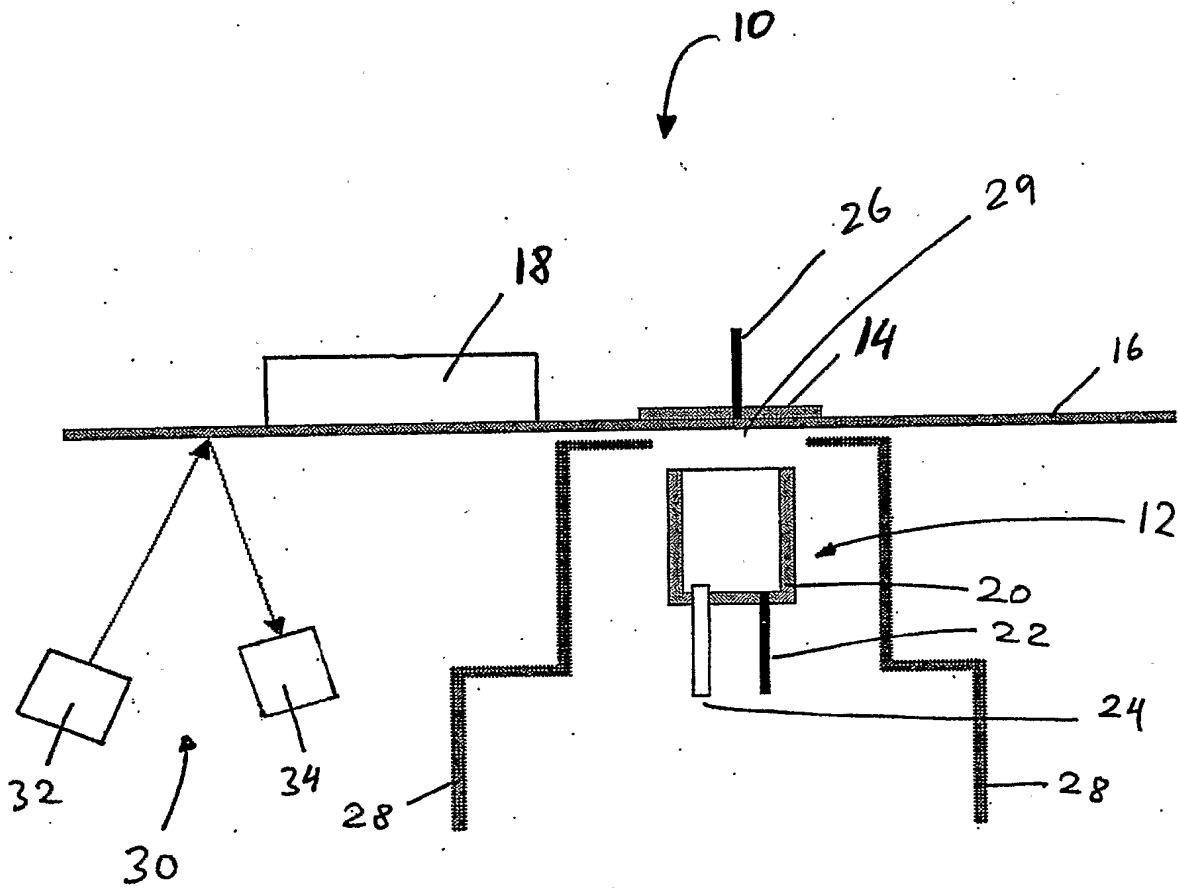


FIG. 1

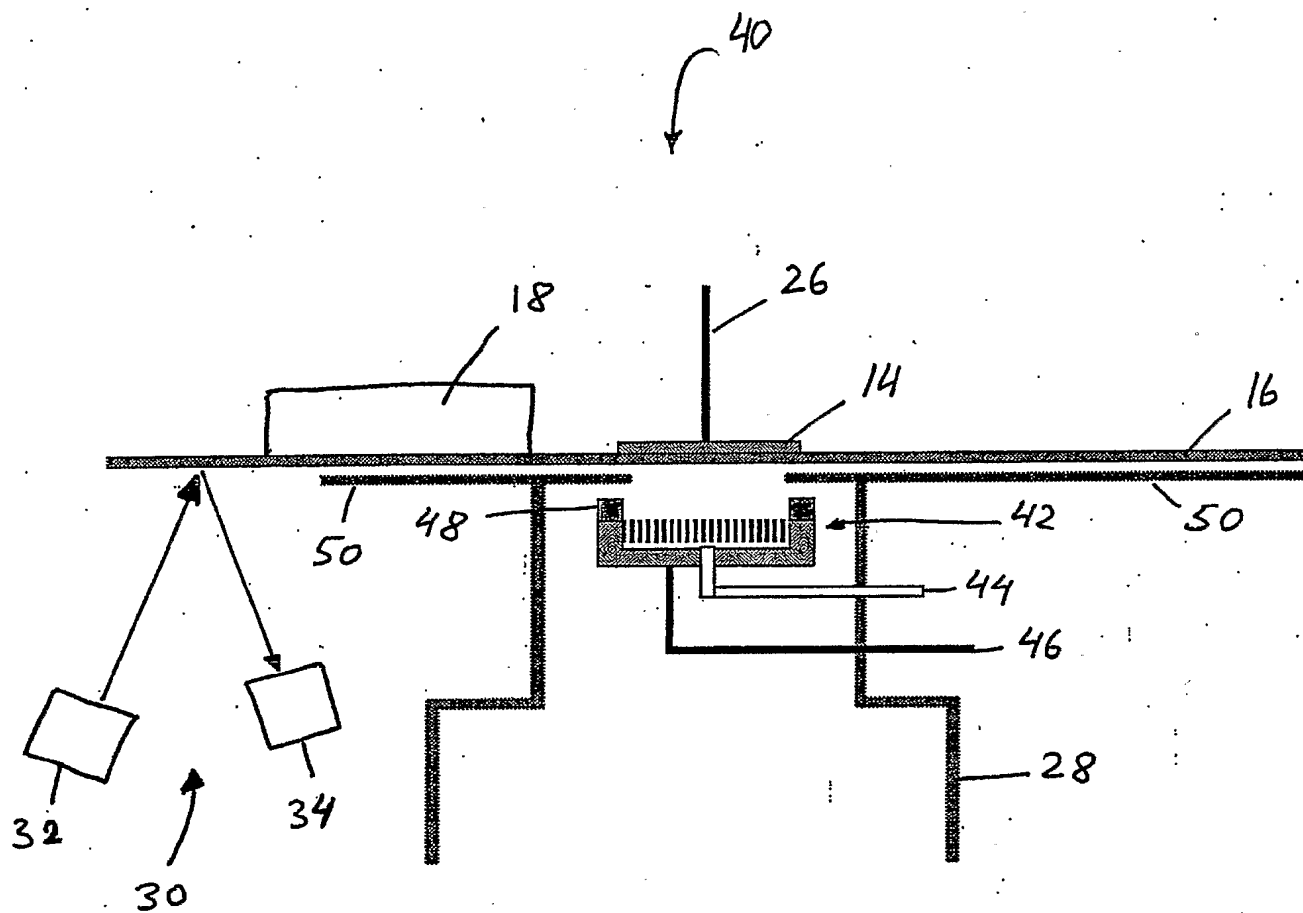


FIG. 2